

ENCAPSULATED DISPLAY DEVICES**CROSS-REFERENCE TO RELATED APPLICATION**

This application is a continuation-in-part of U.S. application Ser. No. 09/427,138, filed Oct. 25, 1999 now U.S. Pat. No. 6,522,067 entitled "Environmental Barrier Material for Organic Light Emitting Device and Method of Making."

BACKGROUND OF THE INVENTION

The present invention relates generally to display devices, and more particularly to environmentally sensitive display devices encapsulated in barrier stacks to prevent degradation.

There is a need for versatile visual display devices for electronic products of many different types. Many different display devices are presently being used, including liquid crystal displays (LCDs), light emitting diodes (LEDs), light emitting polymers (LEPs), electronic signage using electrophoretic inks, electroluminescent devices (EDs), and phosphorescent devices. Many of these display devices are environmentally sensitive. As used herein, the term environmentally sensitive display device means display devices which are subject to degradation caused by permeation of environmental gases or liquids, such as oxygen and water vapor in the atmosphere or chemicals used in the processing of the electronic product.

Although many current displays use glass substrates, there is a trend toward the use of plastic substrates. Plastic substrates are critical to future generations of electronic products and associated technologies because they are light weight, impact resistant, and cost effective. However, the gas and liquid permeation resistance of plastics is poor, often several orders of magnitude below what is required for sustained device performance. Barrier coatings are applied to substrates to decrease their gas and liquid permeability. Barrier coatings typically consist of single layer thin film inorganic materials, such as Al, SiO₂, Al₂O₃, and Si₃N₄ vacuum deposited on polymeric substrates. The best single layer coatings reduce oxygen and water vapor permeability to levels of about 0.1 to 1.0 cc/m²/day and about 0.1 to 1.0 g/m²/day, respectively. (Conditions were not reported. The testing is believed to be at 23° C.) However, many displays require oxygen permeability levels of between about 10⁻⁶ and 10⁻⁵ cc/m²/day, and water vapor permeability levels between about 10⁻⁴ and 10⁻² g/m²/day. The environmental sensitivity of the display devices limits the lifetime, reliability, and performance of devices constructed on plastics, which has retarded the development of display devices made with plastic substrates.

Thus, there is a need for an improved, lightweight, barrier construction which can be used to encapsulate environmentally sensitive display devices and prevent the deterioration caused by gas and liquid permeation, and for methods for making such encapsulated environmentally sensitive display devices.

SUMMARY OF THE INVENTION

The present invention meets these need by providing an encapsulated display device and a method for making such a device. The device includes a substrate, an environmentally sensitive display device adjacent to the substrate, and at least one first barrier stack adjacent to the environmentally sensitive display device. By adjacent, we mean next to, but not necessarily directly next to. There can be additional

layers intervening between the adjacent layers. The barrier stack encapsulates the environmentally sensitive display device. It includes at least one first barrier layer and at least one first polymer layer. The encapsulated display device optionally includes at least one second barrier stack located between the substrate and the environmentally sensitive display device. The second barrier stack includes at least one second barrier layer and at least one second polymer layer.

Preferably, either one or both of the first and second barrier layers of the first and second barrier stacks is substantially transparent. At least one of the first barrier layers preferably comprises a material selected from metal oxides, metal nitrides, metal carbides, metal oxynitrides, metal oxyborides, and combinations thereof.

Either one of the first and second barrier layers can be substantially opaque, if desired. The opaque barrier layers are preferably selected from opaque metals, opaque polymers, opaque ceramics, and opaque cermets.

The substrate can either be flexible or rigid. It is preferably made of a flexible substrate material, such as polymers, metals, paper, fabric, and combinations thereof. If a rigid substrate is used, it is preferably a ceramic (including glass), a metal, or a semiconductor.

The polymer layers of the first and second barrier stacks are preferably acrylate-containing polymers. As used herein, the term acrylate-containing polymers includes acrylate-containing polymers, methacrylate-containing polymers, and combinations thereof. The polymer layers in the first and/or the second barrier stacks can be the same or different.

The environmentally sensitive display device is preferably selected from liquid crystal displays, displays using electrophoretic inks, light emitting diodes, electroluminescent devices, and phosphorescent devices.

The encapsulated display device can include additional layers if desired, such as polymer smoothing layers, scratch resistant layers, or other functional layers. The encapsulated display device can also include a lid adjacent to the at least one first barrier stack.

The present invention also involves a method of making the encapsulated display device. The method includes providing a substrate having an environmentally sensitive display device thereon, and placing at least one first barrier stack over the environmentally sensitive display device to encapsulate the environmentally sensitive display device. The barrier stack includes at least one first barrier layer and at least one first polymer layer.

The environmentally sensitive display device can be placed on the substrate by deposition or by lamination. The at least one first barrier stack can be placed over the environmentally sensitive display device by deposition, preferably vacuum deposition, or by laminating the barrier stack over the environmentally sensitive device. The lamination can be performed using an adhesive, solder, ultrasonic welding, pressure, or heat.

A second barrier stack can be placed on the substrate before the environmentally sensitive display device is placed there. The second barrier stack includes at least one second barrier layer and at least one second polymer layer. The second barrier stack can be deposited on the substrate, preferably by vacuum deposition.

The substrate can be removed from the encapsulated environmentally sensitive display device, if desired.

Accordingly, it is an object of the present invention to provide an encapsulated display device, and to provide a method of making such as device.